Design Data 41

American Concrete Pipe Association

Manhole Flotation

Introduction

The proper functioning of a sewer system is dependent to a large degree on the performance of its appurtenances, and especially its manholes. As with many buried structures, the proper design of manholes should take into account the effect of the water table and its specific effect on installation and operating conditions.

The Buoyancy Concept

From a fluid dynamics standpoint, the buoyant force acting on a submerged object is equal to the weight of fluid which that object displaces. In the case of a buried structure or manhole, this concept is applicable when a high ground water table or other subaqueous condition exists. As with the design of buried pipe, flotation should be checked when conditions such as the use of flooding to consolidate backfill, flood planes or future man-made drainage changes are anticipated.

Manhole Buoyancy Analysis

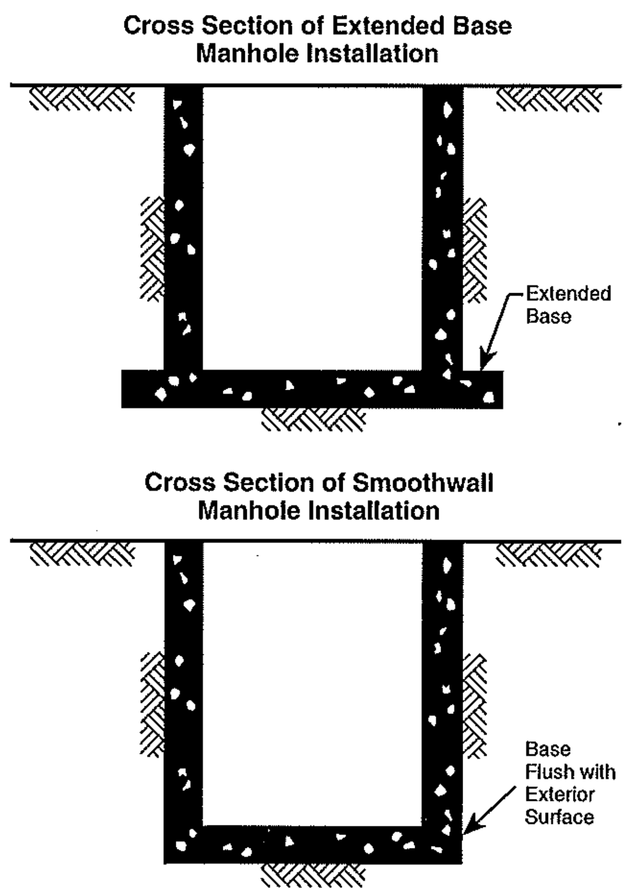
Vertical manhole structures of two types (Figure 1) are generally constructed, and each type should be considered when analyzing the flotation potential. The first case to be considered is a structure in which the base does not extend past the walls of the manhole. This structure will be called a smooth-wall manhole installation. Smooth-wall manholes utilize the weight of the structure itself and the downward frictional resistance of the soil surrounding the manhole to resist the upward buoyant force. Some manufacturers and designers use an extended base to provide additional resistance to buoyant forces. These structures are constructed with a lip extending beyond the outer edges of the manhole and are termed extended base manhole installations. An extended base manhole uses the additional weight of soil above the lip as well as its self-weight and frictional forces to resist flotation.

Design methods, using basic soil mechanics to determine if a manhole is susceptible to flotation, are presented here to aid the engineer in their design of the structure.

Shear Strength

For an installed and backfilled structure to actually

Figure 1 Manhole Installations



"float", or exhibit upward movement, the buoyant forces must overcome both the weight of the structure and the shear between the walls and the soil. Shear strength is defined in soils engineering to be the resistance to sliding of one mass of soil against another. Shear strengths, as typically provided, are a measure of the resistance to sliding within a single uniform soil mass. The shear strength of a soil has traditionally been related by two strength parameters: internal friction and cohesion.

Shear strength (τ_f) as typically expressed by Coulomb's equation is:

$$\tau_f = c + \sigma (\tan \varphi)$$

where: τ_f = shear strength, lbs/ft² (kPa)
c = cohesion, lbs/ft² (kPa)
φ = angle of internal friction, degrees
σ = normal stress on the sliding surface or shear plane, lbs/ft² (kPa)

Certain analyses require shear strength between dissimilar substances, most commonly soil and concrete. This shear strength is an apparent rather than true shear resistance and is usually called sliding resistance.

Sliding resistance equations typically use a coefficient of friction (f) to represent the friction between the two dissimilar materials. The equation for sliding resistance is therefore defined as:

$$r_{sliding} = c + \sigma f$$

Cohesionless Soils

A uniform cohesionless soil (sands and gravels) by definition has a cohesion coefficient, (c), equal to zero. The sliding resistance equation, therefore, reduces to:

$$r_{sliding} = c + \sigma f$$

Several different references are available which address values for the coefficient of friction. Typical values of the friction coeffficient (f) from the literature generally range between .35 for silts and .55 for coarse-grained gravels against concrete. The friction coefficient is a function, however, of soil material type, manhole material, outside manhole profile, compaction levels, and material homogeneity. The designer is cautioned to solicit site specific materials properties and appropriate design values for individual projects from professionals in the geotechnical field.

Table 5.5.5B of the American Association of State Highway and Transportation Officials (AASHTO) Standard Specification for Highway Bridges, 15th Edition (1992), lists friction factors for soil materials against concrete. The values in Table 1 are taken from Table 5.5.5B of AASHTO.

Normal Pressure

In order to quantify the sliding resistance, it is necessary to determine the lateral pressure on the walls of the manhole. Assuming the top of the manhole to be at ground surface, the vertical earth pressure is equal to zero at the surface and varies as a function of the soil density with depth to the base. Since the engineer is concerned with flotation, we will initially look at the case where the ground water surface is even with the top of the manhole.

Because a high groundwater condition is being analyzed, the designer must determine the effective weight of soil solids which are buoyed up by the water pressure. This submerged soil weight becomes less than that for the same soil above water and is given by:

$$\gamma_{sub} = \gamma_s \left[1 - \frac{1}{S.G.} \right]$$

where: γ_{sub} = effective unit weight submerged, lbs/ft³ (N/m³)
γ_s = unit weight of dry soil, lbs/ft³ (N/m³)
S.G = Specific Gravity of the soil, dimensionless

Specific gravity is based only upon the solid portion of a material. Soil is a conglomerate of minerals, all having differing specific gravities, and containing voids between the soil grains. For this analysis, a specific gravity for the soil particles as they occur naturally will be used. Specific gravity ranges from 2.50 to 2.80 for most soils, with a majority of soils having a specific gravity near 2.65.

Vertical manhole structures normally experience ring compression and therefore are subject to active earth

Table 1

Ultimate Friction Factors and Friction Angles for Dissimilar Materials from AASHTO Table 5.5.5B

Interface Materials	Friction Angle, δ (Degrees)	Friction Factor, f tan δ (DIM)
Formed concrete or concrete sheet piling against the following soils:		
• Clean gravel, gravel-sand mixture, well-graded rock fill with spans	22 to 26	0.40 to 0.50
• Clean sand, silty sand-gravel mixture, single size hard rock fill	17 to 22	0.30 to 0.40
• Silty sand, gravel or sand mixed with silt or clay	17	0.30
• Fine sand silt, nonplastic silt	14	0.25

pressures. The magnitude of the normal pressure, at a given depth (d) is determined by both the effective weight of the soil pushing against the wall of the structure and the water pressure caused by the submerged condition (Figure 2). This normal force is given by the following equation:

$$\sigma = (K_a \gamma_{sub} + \gamma_w)\, d$$

where: σ = Normal stress against wall, lbs/ft^2 (kPa)
K_a = Active lateral earth pressure coefficient, dimensionless
d = Depth at which normal pressure acts, ft (m)
γ_w = Unit weight of water, 62.4 lbs/ft^3 (9.8 kN/m^3)

However, water exerts a negligible friction force on the wall of the manhole. Therefore, the normal stress considered for friction is based on the effective vertical stress:

$$\sigma = (K_a \gamma_{sub})\, d$$

where: σ = Effective normal stress against wall, lbs/ft^2 (N/m^2)

Estimates of active lateral earth pressure vary with soil type. Marston's values included in Table 3, as well as commonly accepted values, indicate that a lateral earth pressure coefficient of 0.33 is adequate for most soil materials.

Sliding Resistance

The total sliding resistance available to resist flotation at a given depth (d) is the combination of the unit resistance ($r_{sliding}$) acting over the exterior circumferential surface of the manhole.

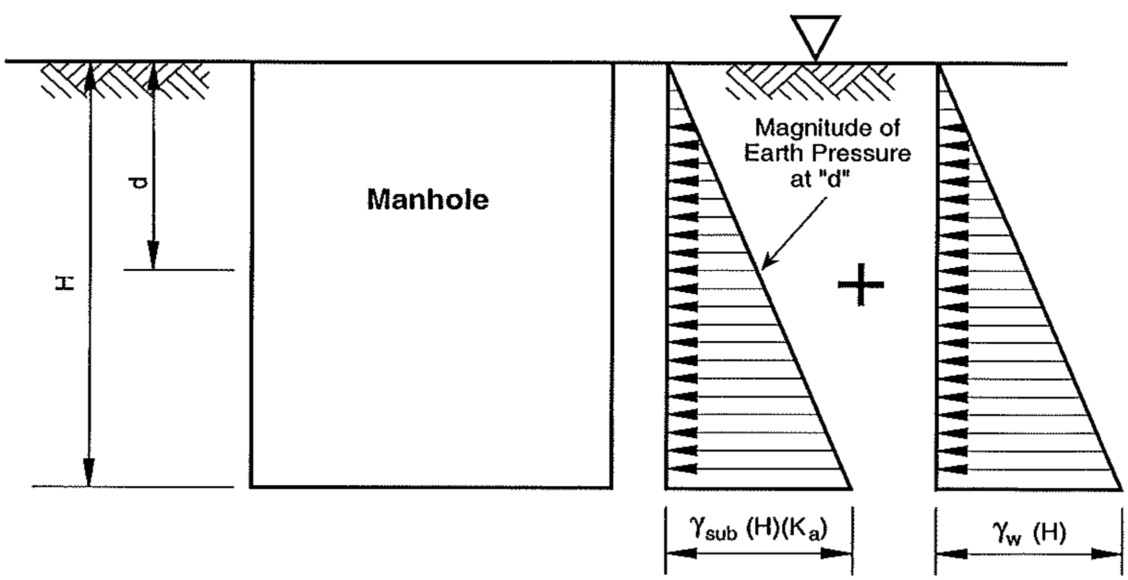
The assumptions of uniform soil material and ring compression for the structure make the unit resistance equal at a given depth around the circumference of the structure. The unit resistance available at depth (d) is therefore defined as:

$$r_{sliding} = \sigma\,(f)\,(\pi)\,(B_d)$$

where: $(\pi)(B_d)$ = circumference of manhole, ft (m)
f = friction factor, dimensionless

Since the vertical and lateral pressure, and hence the unit sliding resistance, varies with depth, the sliding resistance available for the total structure, $R_{sliding}$, is equal to the summation of the various $r_{sliding}$ values over the height (H) of the structure from the ground surface to the bottom of the base slab.

Figure 2



$$R_{sliding} = \sum_{d \to 0}^{H} (r_{sliding})$$

Since the pressure exerted varies linearly with depth from 0 at the ground surface to $(K_a \gamma_{sub})H$ at the manhole base, (Figure 3) the total resultant pressure acting on the manhole can be defined as:

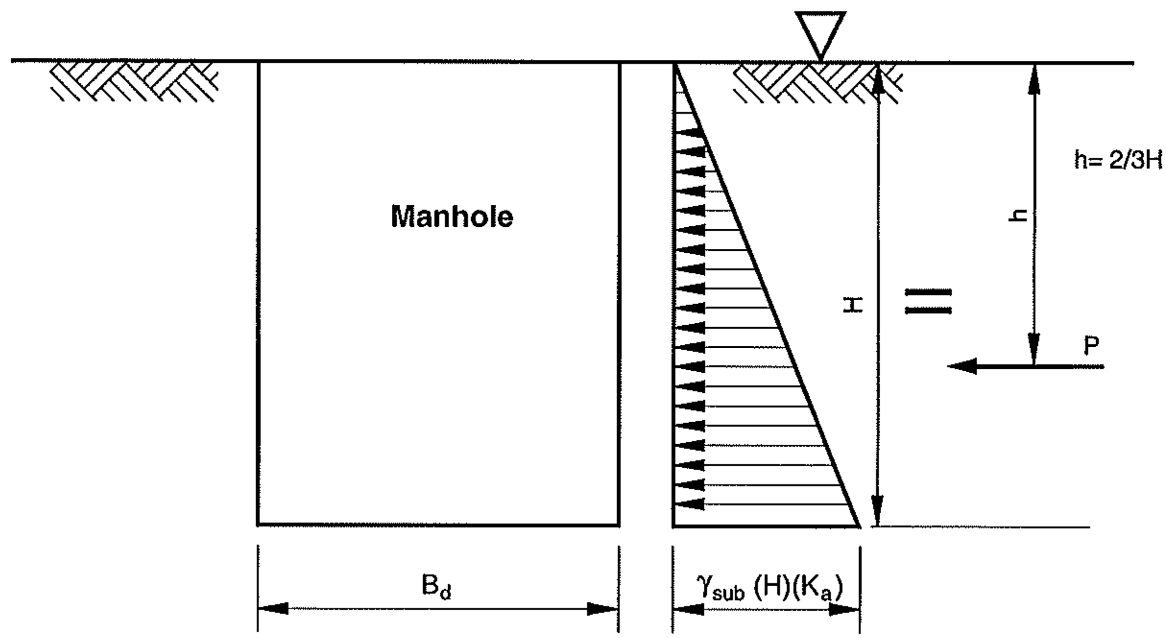
$$P = [(K_a \ \gamma_{sub}) H] \left(\frac{H}{2}\right)$$

With P defined, $R_{sliding}$ can be calculated as:

$$R_{sliding} = P (f) (\pi) (B_d)$$

NOTE: The lateral pressure $(\gamma)(H)$ reaches a maximum limit at approximately 15 B_d. Most manhole installations are not that deep. However, lateral pressure must be considered for extremely deep installations.

Figure 3



Groundwater Level Effect

In order to design for the most conservative case and also simplify the design procedure, the groundwater level was earlier assumed to exist at the top of the manhole structure. If the designer is assured that the groundwater surface is below grade level, and will remain there, the design procedure can be modified accordingly.

For a structure where the groundwater surface is below grade level (Figure 4) the effective unit weight of the soil will vary above and below the groundwater surface. Since the groundwater level affects the magnitude of the normal forces at various depths, these force are calculated in separate parts as follows:

Zone A - the total soil force from the ground level to the water table;

$$P_{dry} = [(\gamma_s) (Y) (K_a)] \left(\frac{Y}{2}\right)$$

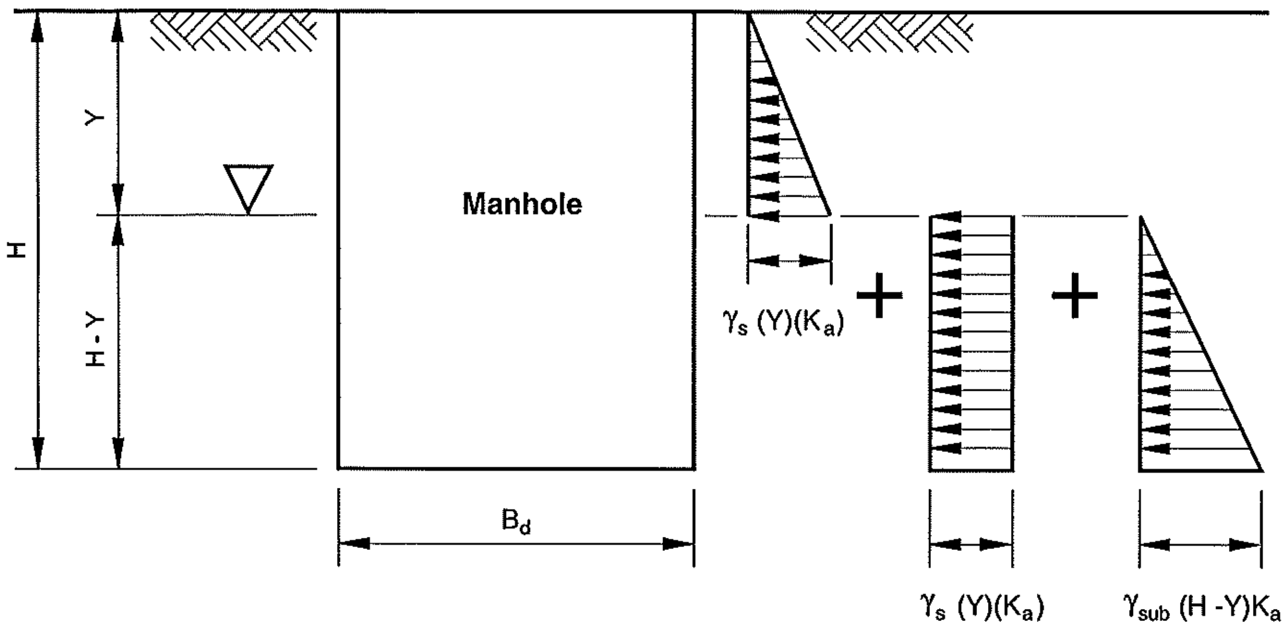
Zone B - the total effective force of the earth against the wall below the water table

$$P_{sub} = (H\text{-}y) [(\gamma_s)(y)(K_a)] + \frac{1}{2} (\gamma_{sub})(H\text{-}y)(K_a)$$

The sliding resistance can be found from:

$$R_{sliding} = (P_{dry} + P_{sub}) (f)(\pi)(B_d)$$

Figure 4



Cohesive Soils

In clays and silty soils the cohesion coefficient (c) depends on the nature and consistency of the material. The angle of internal friction for clays (φ) can vary from 0° to 30°. Many soils are either dominantly cohesive or noncohesive and, for simplification in engineering computations, are considered to be either one or the other. Applying this assumption, the (φ) value for completely saturated clays is zero, and the sliding resistance equation reduces to:

$$r_{sliding} = c$$

The value of c can be derived as a fraction of the unconfined compressive strength (q_u) and is generally represented as follows:

$$c = \frac{q_u}{2}$$

Typical values for the unconfined compressive strength of clays are shown in Table 2:

Table 2

Consistency	Field Identification	Unconfined Compressive Strength q_u, psf (kPa)
Very Soft	Easily penetrated several inches by fist	Less than 500 (24)
Soft	Easily penetrated several inches by thumb	500-1,000 (24 - 48)
Medium	Can be penetrated several inches by thumb with moderate effort	1,000-2,000 (48 - 96)
Stiff	Readily indented by thumb but penetrated only with great effort	2,000-4,000 (96 - 192)
Very Stiff	Readily indented by thumbnail	4,000-8,000 (192 - 384)
lHard	Indented with difficulty by thumbnail	Over 8,000 (384)

The designer is cautioned to use site specific values or, moreover, those determined to be valid by a professional skilled in the determination of geotechnical parameters. The values shown in Table 2 may not apply to individual project conditions.

With the value of (q_u) defined, $R_{sliding}$ is defined as:

$$R_{sliding} = \pi\,(B_d)\left(\frac{q_u}{2}\right)(H)$$

or

$$R_{sliding} = \pi\,(B_d)\,(c)\,(H)$$

Buoyancy Analysis

As previously stated, the buoyant force (B) is equal to the weight of water displaced by the manhole structure. This force is defined as the density of water multiplied by the volume of water displaced by the structure, and is expressed as:

$$B = \gamma_W \left(\pi\,\frac{B_d{}^2}{4}\right) H$$

where: γ_w = density of water = 62.4 lbs/ft^3 (9.8 kN/m^3)

Design Safety Factor

This buoyant force (B) is resisted by the weight of the manhole assembly (W) and the total sliding resistance ($R_{sliding}$).

For the structure to be stable:

$$W + R_{sliding} \geq B$$

Keeping this relationship in mind, a design safety factor for buoyancy is easily derived:

$$F.S._{buoyancy} = \frac{W + R_{sliding}}{B}$$

Generally, if the weight of the structure is the primary force resisting flotation than a safety factor of 1.0 is adequate. However, if friction or cohesion are the primary forces resisting flotation, then a higher safety factor would be more appropriate to account for the variability of the soil properties.

Extended Base Manhole Installations

Installations in which the base slab extends beyond the outer face of the manhole wall (Figure 5) are treated only slightly differently than the smooth-wall installations. This case can be analyzed as a smooth-wall installation with the following exceptions.

1) The diameter of the base (D_b) should be used instead of using the external diameter of the structure itself (B_d) to determine the perimeter of the failure cylinder.
2) Since the failure mode is a backfill shear failure, the coefficient of friction (f) for granular materials should be determined by:

   $$f = \tan \varphi$$

   where: φ = angle of internal friction for the backfill material

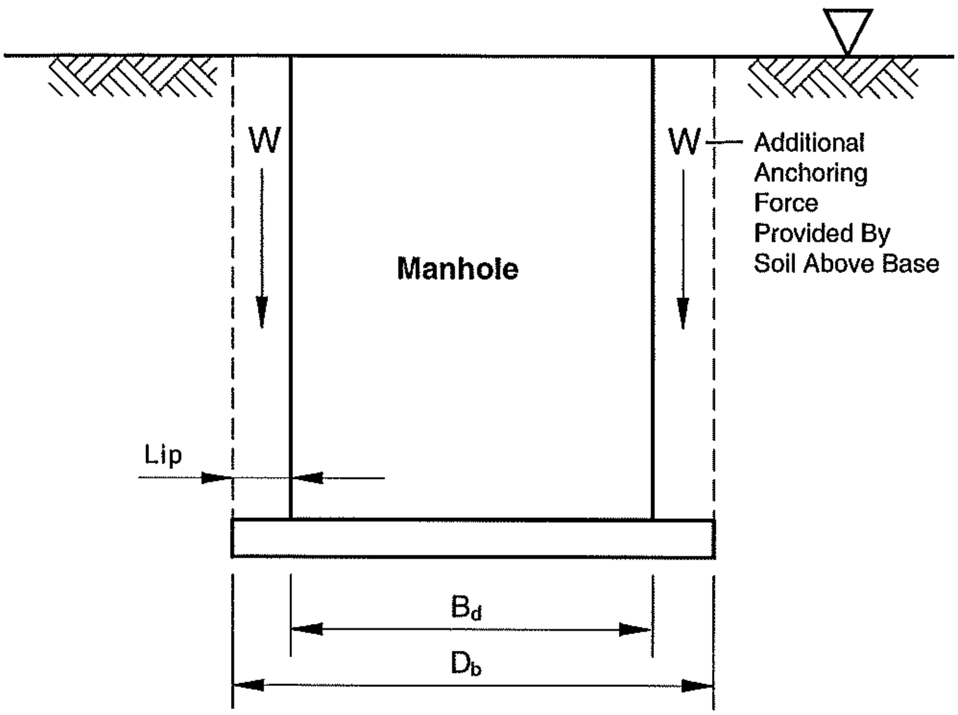
   For an initial estimate, a friction coefficient may be taken from Table 3 which gives soil friction

Table 3

Approximate Safe Working Values of the Constants to Be Used In Calculating the Loads on Pipes in Ditches

Ditch Fill	w=Unit Weight of Backfill (lbs/ft3)	K= Ratio of Lateral to Vertical Earth Pressures	u=coefficient of Friction Against Sides of Trenches
Partly Compacted Top Soil	90	0.33	0.50
Saturated Top Soil	110	0.37	0.40
Partly Compacted Damp Yellow Clay	100	0.33	0.40
Saturated Yellow Clay	130	0.37	0.30
Dry sand	100	0.33	0.50
Wet Sand	120	0.33	0.50

Figure 5



coefficients developed by Marston for soils placed in a trench with a similar insitu soil.

3) The additional effective weight of the backfill in the cylinder above the lip can be added as an anchoring force.

The designer is advised to use caution in the analysis of extended base structures because the parameters employed vary greatly with material properties, compaction levels, and friction factors assumed between native and compacted soils. In the case of extended-base structures, an alternative would be to perform the analysis as detailed for a smooth-wall structure. Although greatly conservative, this analysis can provide a quick check of the particular installation against buoyancy.

Cones and Reducers

If a cone or reducer section is used for a manhole, the designer shall calculate the total weight accordingly. The sliding resistance for the cone or reducer section shall be calculated as follows:

$$P_s = K_a \, \gamma_{sub} \, (H_{bot} - H_{top}) \left(\frac{H_{bot} - H_{top}}{2} \right)$$

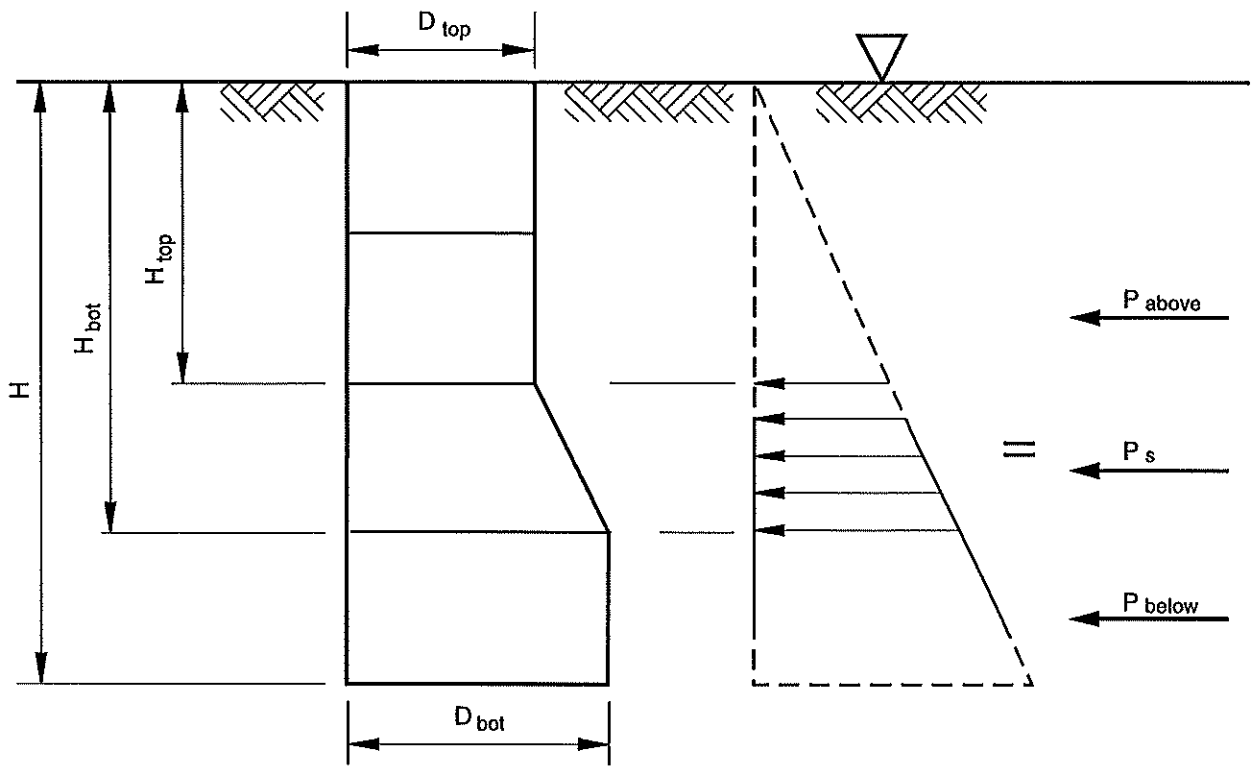
where: $R_{s\text{-}sliding}$ = Sliding resistance of the individual section

$$R_{s\text{-}sliding} = P_s \, (f) \, \pi \left(\frac{D_{bot} + D_{top}}{2} \right)$$

P_s = Resultant horizontal force on the individual section
H_{bot} = Fill height to the bottom of the section
H_{top} = Fill height to the top of the section
D_{bot} = Outside diameter of the bottom of the section
D_{top} = Outside diameter of the top of the section

This sliding resistance can then be added to the sliding resistance of the manhole above and below the section. (Figure 6)

Figure 6



$$P_{above} = [(K_a)\,\gamma_{sub}\,H_{top}\,]\,\left(\frac{H_{top}}{2}\right)$$

$$P_{below} = \gamma_{sub}\,(K_a)\,(H - H_{bot})\left(\frac{H + H_{bot}}{2}\right)$$

$$R_{above} = P_{above}\,(f)\,(\pi)\,(D_{top})$$

$$R_{below} = P_{below}\,(f)\,(\pi)\,(D_{bot})$$

$$R_{total\text{-}sliding} = R_{s\text{-}sliding} + R_{above} + R_{below}$$

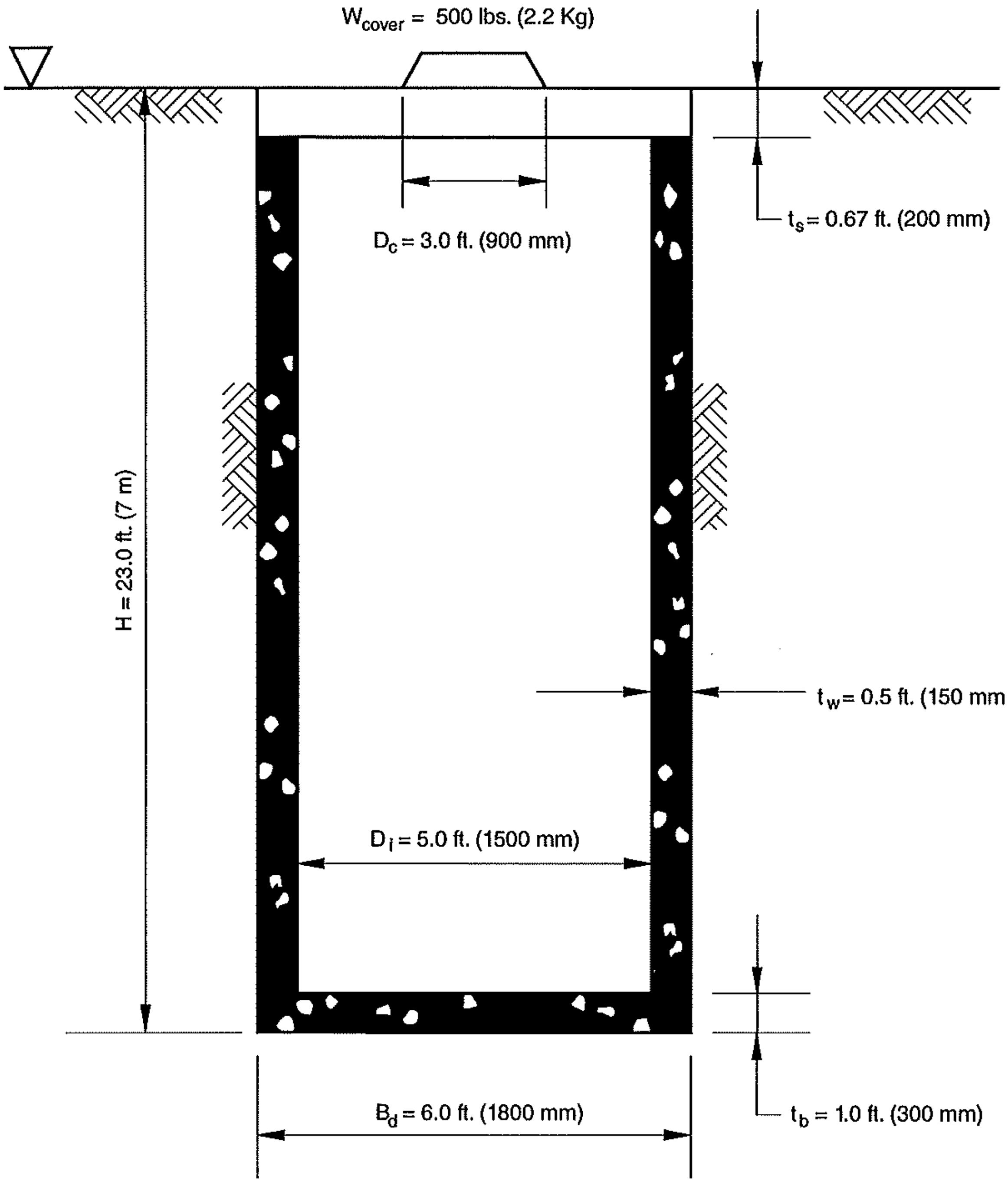
NOTE: An analysis of this detail can generally be avoided by initially assuming the entire structure has the smaller diameter (D_{top}) and calculating the factor of safety against buoyancy.

Example 1:

Given: A 60-inch (1500 mm) diameter manhole, as shown in Figure 7, is to be installed in a clean gravel-sand area to a depth of 23 feet (7 m). The ground water table in the area fluctuates slightly, but in most cases is assumed to be level with the ground surface. A geotechnical analysis at the site yields the following information:

Soil Type	=	Clean sand
Unit Weight of Soil, γ_s	=	120 lbs/ft^3 (18.8 kN/m^3)
Soil Specific Gravity, S.G.	=	2.75

Figure 7



Find: If the manhole installation is stable with respect to buoyancy, and has a minimum factor of safety of 2.0, as required by the project engineer.

Solution: (U.S. Units)

1. Weight of the Structure

$$W_{total} = W_{walls} + W_{base} + W_{top} + W_{cover}$$

Assume the unit weight of concrete, γ_c = 150 lbs/ft^3

$$W_{total} = \left[\pi\left(\left(\frac{B_d}{2}\right)^2 - \left(\frac{D_i}{2}\right)^2\right)(H - t_b - t_s)\,\gamma_c\right] + \left[\frac{\pi}{4}(B_d)^2\,(t_b)\,\gamma_c\right] + \left[\pi\left(\left(\frac{B_d}{2}\right)^2 - \left(\frac{D_c}{2}\right)^2\right)(t_s)\,(\gamma_c)\right] + W_{cover}$$

$$W_{total} = \left[\pi\left(\left(\frac{6}{2}\right)^2 - \left(\frac{5}{2}\right)^2\right)(23\text{-}1\ \text{-}.67)(150)\right] + \left[\frac{\pi}{4}(6)^2(1)(150)\right] + \left[\pi\left(\left(\frac{6}{2}\right)^2 - \left(\frac{3}{2}\right)^2\right)(.67)\,(150)\right] + 500$$

$$W_{total} = 27{,}640 + 4{,}241 + 500$$

$$W_{total} = 34{,}510\ lbs$$

2. Sliding Resistance

From Table 1 the friction coefficient (f) = .30

Assume Ka = 0.33

$$\gamma_{sub} = \gamma_s\left[1 - \frac{1}{\text{S.G.}}\right] = 120\left[1 - \frac{1}{2.75}\right] = 76.4\ lbs/ft^3$$

$$P = \left[(K_a)(\gamma_{sub})\right](H)\left(\frac{H}{2}\right)$$

$$P = [(.33)\,(76.4)]\,(23)\left(\frac{23}{2}\right) = 6{,}665\ lbs/ft$$

$$R_{sliding} = P\,(f)\,(\pi)\,(B_d)$$

$$R_{sliding} = 6{,}665\,(.3)\,(\pi)\,(6) = 37{,}690\ lbs\ (downward)$$

3. Buoyant Force

$$B = \gamma_w\left[\pi\frac{(B_d)^2}{4}\right]H$$

$$B = 62.4\left[\pi\,\frac{(6)^2}{4}\right]23 = 40{,}580\ \text{lbs}\ (upward)$$

4. Factor of Safety

$$FS = \frac{W_{total} + R_{sliding}}{B}$$

$$FS = \frac{34{,}510 + 37{,}690}{40{,}580} = 1.8 < 2.0$$

The factor of safety is not great enough. Therefore, try an extended base with a 1 ft. extension around the entire diameter.

Diameter of Base = D_b = 8ft.

5. Weight of Extended Base Structure

$$W_{base} = \left[\frac{\pi}{4}(D_b)^2(t_b)\gamma_c\right]$$

$$W_{base} = \left[\frac{\pi}{4}(8)^2(1)(150)\right] = 7{,}540 \ lbs$$

$$W_{soil} = \pi\left[\left(\frac{D_b}{2}\right)^2 - \left(\frac{B_d}{2}\right)^2\right](H - t_b)\gamma_{sub}$$

$$W_{soil} = \pi\left[\left(\frac{8}{2}\right)^2 - \left(\frac{6}{2}\right)^2\right](23-1)(76.4) = 36{,}963 \ lbs$$

From Step 1:

W_{walls} = 27,640 lbs
W_{top} = 2,131 lbs
W_{cover} = 500 lbs

W_{total} = 7,540 + 36,963 + 27,640 + 2,131 + 500
= 74,774 lbs

6. Sliding Resistance

From Step 2: P = 6,665 lbs

From Table 3 for sand: f = .5

$R_{sliding}$ = 6,665 (.5) (γ) (8) = 83,760 lbs (downward)

7. Buoyant Force

$$B = \gamma_w\left[\left(\pi\frac{(B_d)^2}{4}\right)H_1 + \left(\pi\frac{(D_b)^2}{4}\right)H_2\right]$$

$$B = 62.4\left[\left(\pi\frac{(6)^2}{4}\right)22 + \left(\pi\frac{(8)^2}{4}\right)1\right]$$

B = 41,952 lbs *(upward)*

8. Factor of Safety

$$FS = \frac{74{,}774 + 83{,}760}{41{,}952} = 3.8 > 2.0 \text{ satisfactory condition}$$

Note: This example was completed to show the differences in design between a smooth-wall and extended base manhole. Most concrete manhole producers only make either a smooth-wall or extended base manhole. Therefore, the specifier may not have the option of adding an extended base.

Solution: (Metric Units)

1. **Weight of the Structure**

$W_{total} = W_{walls} + W_{base} + W_{top} + W_{cover}$

Assume the unit weight of concrete, $\gamma_c = 23.5$ kN/m^3

$$W_{total} = \left[\pi\left(\left(\frac{B_d}{2}\right)^2 - \left(\frac{D_i}{2}\right)^2\right)(H - t_b - t_s)\,\gamma_c\right] + \left[\frac{\pi}{4}(B_d)^2(t_b)\,\gamma_c\right] + \left[\gamma\left(\left(\frac{B_d}{2}\right)^2 - \left(\frac{D_c}{2}\right)^2\right)(t_s)(\gamma_c)\right] + W_{cover}$$

$$W_{total} = \left[\pi\left(\left(\frac{1.8}{2}\right)^2 - \left(\frac{1.5}{2}\right)^2\right)(7-.3-.2)(23.5)\right] + \left[\frac{\pi}{4}(1.8)^2(.3)(23.5)\right] + \left[\pi\left(\left(\frac{1.8}{2}\right)^2 - \left(\frac{.9}{2}\right)^2\right)(.2)(23.5) + 2.2\right]$$

$$W_{total} = 118.8 + 17.9 + 9.0 + 2.2$$

$$W_{total} = 147.9\ kN$$

2. **Sliding Resistance**

From Table 1, the friction coefficient (f) = .30

Assume $K_a = 0.33$

$$\gamma_{sub} = \gamma_s\left[1 - \frac{1}{S.G.}\right] = 18.8\left[1 - \frac{1}{2.75}\right] = 12.0\ kN/m^3$$

$$P = \left[(K_a)(\gamma_{sub})\right](H)\left(\frac{H}{2}\right)$$

$$P = [(.33)(12.0)](7)(3.5) = 96.7\ kN/m$$

$$R_{sliding} = P\ (f)\ (\pi)\ (B_d)$$

$$R_{sliding} = 96.7\ (.3)\ (\pi)\ (1.8) = 164.1\ kN\ (downward)$$

3. **Buoyant Force**

$$B = \gamma_w\left[\pi\frac{(B_d)^2}{4}\right]H$$

$$B = 9.81\left[\pi\frac{(1.8)^2}{4}\right]7 = 174.6\ kN\ (upward)$$

4. **Factor of Safety**

$$FS = \frac{W_{total} + R_{sliding}}{B}$$

$$FS = \frac{147.9 + 164.1}{174.6} = 1.8 < 2.0$$

The factor of safety is not great enough. Therefore, try an extended base with a 0.3 meter extension around the entire diameter.

Diameter of Base = D_b = 2.4m

5. Weight of Extended Base Structure

$$W_{base} = \left[\frac{\pi}{4}\,(D_b)^2\,(t_b)\,\gamma_c\right]$$

$$W_{base} = \left[\frac{\pi}{4}\,(2.4)^2\,(.3)\,(23.5)\right] = 31.9\ kN$$

$$W_{soil} = \pi\left[\left(\frac{D_b}{2}\right)^2 - \left(\frac{B_d}{2}\right)^2\right]\,(H - t_b)\,\gamma_{sub}$$

$$W_{soil} = \pi\left[\left(\frac{2.4}{2}\right)^2 - \left(\frac{1.8}{2}\right)^2\right]\,(7 - .3)\,(12) = 159.1\ kN$$

From Step 1:

W_{walls} = 118.8 kN
W_{top} = 9.0 kN
W_{cover} = 2.2 kN
W_{total} = 31.9 + 159.1 + 118.8 + 9.0 + 2.2
= 321 kN

6. Sliding Resistance

From Step 2: P = 96.7 kN/m

From Table 3 for sand: f = .5

$R_{sliding}$ = 96.7 (.5) (π) (2.4) = 364.6 kN (downward)

7. Buoyant Force

$$B = \gamma_w\left[\left(\pi\frac{(B_d)^2}{4}\right)H_1 + \left(\pi\frac{(D_b)^2}{4}\right)H_2\right]$$

$$B = 9.81\left[\left(\pi\,\frac{(1.8)^2}{4}\right)6.7 + \left(\pi\,\frac{2.4^2}{4}\right)0.3\right]$$

B = 180.6 *kN (upward)*

8. Factor of Safety

$$FS = \frac{321 + 364.6}{180.6} = 3.8 > 2.0 \textit{ satisfactory condition}$$

Note: This example was completed to show the differences in design between a smooth-wall and extended base manhole. Most concrete manhole producers only make either a smooth-wall or extended base manhole. Therefore, the specifier may not have the option of adding an extended base.

Example 2:

Given: The 60-inch (1500mm) diameter manhole in Example 1 (without an extended base) is to be installed in a soft clay soil with native material used to backfill the structure. No geotechnical analysis is available for the site.

Find: If the manhole installation is stable with respect to buoyancy and has a minimum factor of safety of 2.0, as required by the project engineer.

Solution: (U.S. Units)

1. **Weight of the Structure**

   From Example 1, W_{total} = 34,510 lbs.

2. **Sliding Resistance**

   $$\text{For cohesive soils, } R_{sliding} = c = \frac{q_u}{2}$$

From Table 2, qu for soft clay is 500 psf.

$$R_{sliding} = \pi\,(B_d)\,(H)\left(\frac{q_u}{2}\right)$$

$$R_{sliding} = \pi\,(6)\,(23)\left(\frac{500}{2}\right) = 108{,}385\ lbs$$

3. **Buoyant Force**

   From Example 1, the buoyant force, B = 40,580 lbs

4. **Factor of Safety**

   $$FS = \frac{W + R_{sliding}}{B}$$

   $$FS = \frac{34{,}510 + 108{,}385}{40{,}580} = 3.5$$

   $$FS_{required} = 2.0 < 3.5 \text{ satisfactory condition}$$

Solution: (Metric Units)

1. Weight of the Structure

   From Example 1, W_{total} = 147.9 kN

2. **Sliding Resistance**

   $$\text{For cohesive soils, } R_{sliding} = c = \frac{q_u}{2}$$

From Table 2, qu for soft clay is 24 kPa.

$$R_{sliding} = \pi\,(B_d)\,(H)\left(\frac{q_u}{2}\right)$$

$$R_{sliding} = \pi\,(1.8)\,(7)\left(\frac{24}{2}\right) = 475\ kN$$

3. Buoyant Force

From Example 1, the buoyant force, B = 174.6 kN

4. Factor of Safety

$$FS = \frac{W + R_{sliding}}{B}$$

$$FS = \frac{147.9 + 475}{174.6} = 3.5$$

$FS_{required}$ = 2.0 < 3.5 *satisfactory condition*

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